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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150794

INDOOR TEST AND LONG-TERM WEATHERING EFFECTS ON THE THERMAL PERFORMANCE OF THE SOLAR ENERGY SYSTEM (LIQUID) SOLAR COLLECTOR

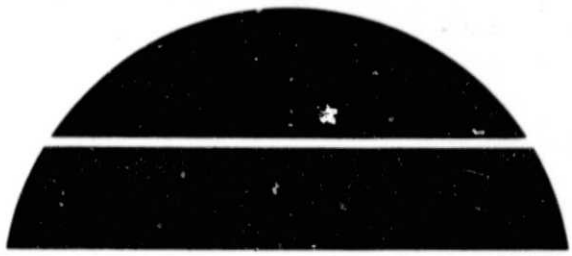
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Contract NAS8-32036

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812
For the U. S. Department of Energy





(NASA-CR-150794) INDOOR TEST AND LONG-TERM WEATHERING EFFECTS ON THE THERMAL PERFORMANCE OF THE SOLAR ENERGY SYSTEM (LIQUID) SOLAR COLLECTOR (Wyle Labs., Inc.) 41 p HC A03/MF A01 CSCL 10A G3/44

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Solar Energy

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16. ABSTRACT

This report contains the procedures used and the results obtained during the evaluation test program on the Solar Energy Systems, Inc., (Liquid) Solar Collector. The narrow flat-plate collector with reflective concentrating mirrors uses water as the working fluid. The double-covered collector weighs 137 pounds and has overall dimensions of about 35" x 77" x 6.75". The test program was conducted to obtain the following information: thermal performance data under simulated conditions, structural behavior under static load, and the effects of long-term exposure to natural weathering. These tests were conducted using the MSFC Solar Test Facility and Solar Simulator.

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1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal performance data on a Solar Energy Systems (S/N 377007) double-covered liquid solar collector under simulated conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in Reference 2.2.

2.0 REFERENCES

2.1	ASHRAE-93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors
2.2	MTCP-DC-SHAC-420	Test Procedure for the Performance Evaluation of Liquid Collectors under Simulated Conditions
2.3	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility

3.0 MANUFACTURER

Solar Energy Systems, Inc.
One Olney Avenue
Cherry Hill, N.J. 08003

3.1 DESCRIPTION OF TEST SPECIMEN

Model Number: 171

Serial Number: 377007

Type: Narrow flat plate absorber with reflective concentrating mirrors

Working Fluid: Water

Gross Collector Area, ft^2: 18.7 ft^2

Overall external dimensions:

Width, Inches:	35.0"
Length, Inches:	77.0"
Thickness, Inches:	6.75"
Aperture area, ft^2:	17.1'

Collector glazing: Double

Weight, lbs: Empty - 137 lbs.
Full - 141 lbs.

4.0 SUMMARY

This test program was conducted to evaluate the thermal performance of a Solar Energy Systems liquid collector under simulated conditions. The test conditions and the data obtained during the tests conducted on the simulator are listed in Table I for thermal performance test. A graphic presentation of the data obtained is also presented in Figure 3. In addition, a time constant test and incident angle modifier test were conducted to determine the transient effect and the incident angle effect on the collector. The results of these tests are presented in Figures 4 through 6 and Table II. Results of the collector load test are listed in Table III.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests were performed at ambient conditions existing in Building 4619 at the time of the tests and listed in Tables I and II.

5.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4 C, Metrology and Calibration. The collector liquid loop flow diagram is shown in Figure 1. Instrumentation locations on the test loop and the collector are depicted in Figure 2. A listing of the equipment used in the tests follows.

Apparatus	Manufacturer/Model	Range/Accuracy
Platinum Resistance Thermometer	Supplied by Collector Manufacturer	0-500°F ± 2°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft^2·Hr ± 3%
Liquid Loop	MSFC Supplied	.1 - 1.2 GPM
Directional Anemometer	MSFC Supplied	0 - 30 MPH
Flowmeter	Foxboro/1/2-2 81T3C1	.1 - .91 ± 1% GPM
Platinum Resistance Thermometer	Minco Products	60-250°F ± .5°F
Strip Chart Recorder	Mosley 680	5-500 mv ± 2%
Floor Fan	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Differential Pressure Sensor	Statham	0-10 PSID ± 1%
Platinum Resistance Thermometer	Hy-Cal	-50 - 400°F ± 1°F

6.0 REQUIREMENTS, PROCEDURES AND RESULTS

6.1 Collector Thermal Efficiency Test

6.1.1 Test Requirements

Thermal performance evaluation data shall be obtained at inlet temperatures of 0, 25, 50, 100, and 140°F above ambient temperature at liquid flow rate of 275 lb/hr at insolation rates of 250 and 300 BTU/Hr·Ft^2 and a wind speed of 7.5 mph. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet liquid temperature.
3. Collector outlet liquid temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Liquid flow rate.
7. Insolation rate.
8. Wind speed.

6.1.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with respect to the floor.
3. Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the top of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all pipes.
5. Assure that data acquisition system is operational.
6. Start liquid flow loop and establish a flow rate of 275 lb/hr.
7. Establish the wind speed of 7.5 mph.
8. Power up simulator and establish a solar flux level of 250 BTU/Ft^2·Hr.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.1.2 Test Procedure (Continued)

9. Determine the ambient air temperature.

10. Adjust the inlet temperature of the collector to the ambient air temperature value.

11. After steady state conditions have been established, record data for a minimum of five minutes.

12. Repeat steps 8, 9, 10 and 11, changing the flux level and liquid inlet temperature as necessary until data has been obtained for each test condition specified in Paragraph 6.1.1.

13. Upon completion of testing, power down simulator and liquid loop.

14. Inform data control group that simulator operation has terminated.

6.1.3 Test Results

The results obtained during these tests are contained in Figure 3 and Table I.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.2 Collector Time Constant Test

6.2.1 Test Requirements

In accordance with ASHRAE 93-77, the time constant test shall be conducted by abruptly reducing the flux level to zero. Inlet temperature shall be kept to within + 2°F of ambient, with a liquid flow rate of 275 lb/hr. The differential temperature across the collector shall be recorded to determine the time required to reach the condition of

$$\frac{Te - Ti}{Te_{ini} - Ti} = .368$$

where

Te = Outlet temperature

Te_{ini} = Initial outlet temperature

Ti = Inlet temperature.

The following data shall be recorded during the test:

1. Ambient temperature.
2. Collector inlet temperature.
3. Collector outlet temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Liquid flow rate.
7. Insolation rate.

6.2.2 Test Procedure

1. Mount the collector on test table at 45° from the horizontal and assure that solar simulator surface is parallel to the collector surface.
2. Assure that data acquisition system is operational.
3. Adjust the liquid flow rate to 275 lb/hr.
4. Adjust the liquid inlet temperature to within ± 2°F of ambient.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.2.2 Test Procedure (Continued)

5. Adjust the flux level to 300 BTU/Ft^2·Hr.

6. Monitor the differential temperature across the collector.

7. Allow the system to stabilize at above conditions for at least 5 minutes.

8. Turn off the solar simulator.

9. Monitor the differential temperature until the ratio of $\frac{Te - Ti}{Te_{ini} - Ti}$ is less than .30.

10. Upon completion of testing, power down simulator and liquid loop.

11. Inform data control group that simulator operation has terminated.

6.2.3 Test Results

The results obtained during this test are shown in Figure 4.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3 Collector Incident Angle Modifier Test

6.3.1 Test Requirements

The collector incident angle modifier test shall be conducted at north-south radiation incident angle of 0 degrees. The east-west radiation incident angles shall be 15, 30, 45 and 60 degrees. The liquid flow rate shall be 275 lb/hr with inlet temperature controlled to within ± 2°F of ambient at the insolation rate of 300 BTU/Ft^2·Hr and 0 mph wind. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet liquid temperature.
3. Collector outlet liquid temperature.
4. Collector differential temperature.
5. Liquid flow rate.
6. Insolation rate.

6.3.2 Test Procedure

1. Mount the collector on the test table at incident angle of 15°.
2. Adjust the liquid flowrate to 275 lb/hr.
3. Adjust the solar simulator flux level to 300 BTU/hr·ft^2.
4. Adjust the inlet temperature to ambient ± 2°F.
5. Measure the flux level at 9 locations on the test plane.
6. Record data for 5 minute stabilized period.
7. Repeat above steps for incident angles of 30°, 45° and 60°.
8. Upon completion of testing, power down simulator and liquid loop.
9. Inform data control group that simulator operation has terminated.

6.0 REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.3.3 Test Results

Data obtained from this test program were analyzed according to ASHRAE 93-77 and reported in Table II and graphic format in Figures 5 and 6.

6.0 TEST REQUIREMENTS, PROCEDURES AND RESULTS (Continued)

6.4 Collector Load Test

6.4.1 Test Requirements

One solar collector shall be subjected to load testing. The specified load requirements are listed in Table III. The collector shall be mounted as indicated in Figure 8 but oriented such that the glazing is horizontal. Uniform loads shall be applied by means of a transparent flexible diaphragm which can be covered with a uniform layer of transparent liquid of varying depths to obtain the desired load variations.

6.4.2 Test Procedure

1. Mount the collector in the horizontal plane.
2. Place the load frame with liner over the collector.
3. Fill the load frame liner with water to a level corresponding to the Step 1 load of Table III and let stand for five minutes.
4. Drain and remove the load frame.
5. Flush the collector exposed surface with water and inspect for leaks.
6. If the collector leaked or was damaged due to the load, record and indicate what the load level is.
7. If the collector does not leak and is not damaged, record the load level and repeat steps 3 through 5 for the next load level.

6.4.3 Test Results

The results of this test are tabulated in Table III.

7.0 ANALYSIS

7.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf}\left(t_{f,e} - t_{f,i}\right)}{I} \qquad (1)$$

where:

q_u = rate of useful energy extracted from the Solar Collector (BTU/Hr)

A = Gross collector area (Ft^2)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector ($Lbm/Ft^2 \cdot Hr$)

C_{tf} = Specific heat of the transfer liquid ($BTU/Lb \cdot °F$)

$t_{f,e}$ = Temperature of the transfer liquid leaving the collector (°F)

$t_{f,i}$ = Temperature of the transfer liquid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)\, C_{tf}\left(t_{f,e} - t_{f,i}\right)}{(IA)} = \frac{\dot{M}\, C_{tf}\left(t_{f,e} - t_{f,i}\right)}{P_i} \qquad (2)$$

Notice that:

$P_i = IA$ = Total Power Incident on the Collector.

$\dot{m}A = \dot{M}$ = Total Mass Flow Rate through the Collector.

Therefore $\dot{M}\, C_{tf}(t_{f,e} - t_{f,i})$ = Total Power Collected by the Collector.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{Pabs}{Pinc} \qquad (3)$$

where:

Pabs = Total collected power

Pinc = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \qquad (4)$$

or from Equation (2), collector efficiency is defined by the equation:

$$\% \text{ Eff.} = \frac{\dot{M} C_{tf} (t_{f,e} - t_{f,i})}{Pi} \times 100 \qquad (5)$$

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-second intervals. The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left((t_i - t_a) / I \right)$$

where:

t_i = Liquid inlet temperature (°F)

t_a = Ambient temperature (°F)

I = Incident flux per unit area ($BTU/Hr \cdot Ft^2$)

The abscissa term $\left((t_i - t_a) / I\right)$ was used to normalize the effect of operating at different values of I, t_i and t_a. The results are found in Figure 3.

The result of second order polynomial analysis is shown in Figure 3. The second order polynomial to best describe the test results is:

$$\text{Efficiency} = a_0 + a_1 \mathcal{I} + a_2 \mathcal{I}^2$$

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$$\tau = (t_i - t_a)/I$$

and the coefficients are determined to be:

Flow Rate (Lbm/Hr)	275
a_0	0.628
a_1	-0.776
a_2	-0.055

7.0 ANALYSIS (Continued)

7.2 Time Constant Test

Two methods are proposed by ASHRAE 93-77 for conducting a time constant test. However, due to facility limitations, only the first method could be used. This method consisted of shutting down the simulator and maintaining a constant flow rate and inlet temperature while obtaining data.

According to the definition of time constant given in 93-77, it is the time required for the ratio of the differential temperature at time τ to the initial differential temperature to reach .368. It can be expressed as:

$$\frac{T_{f,e}\,\tau - T_{f,i}}{T_{f,e,ini} - T_{f,i}} = .368 \qquad (1)$$

if the inlet liquid temperature can be controlled to equal the ambient air temperature,

where:

$T_{f,e,\tau}$ = Exit liquid temperature at time

$T_{f,i}$ = Inlet liquid temperature

$T_{f,e,ini}$ = Initial exit liquid temperature.

From Figure 4 the time constant was determined to be 45 seconds.

7.0 ANALYSIS (Continued)

7.3 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-77 for incident angle modifier tests. For the MSFC Solar Simulator Facility, only method 1 (tilting the collector) is applicable. The collector was adjusted so that the incident radiation angles were 15°, 30°, 45°, and 60° to the normal of the collector surface.

According to 93-77, the incident angle modifier is defined as

$$K_{\alpha\tau} = \frac{\eta}{F_R\,(\tau\alpha)n} \qquad (1)$$

where η = efficiency at tilted angle

$F_R(\alpha\tau)n$ = Intercept of efficiency curve at normal incident angle.

For equation (1) to be applicable, the inlet liquid temperature must be controlled to within $\pm$ 2°F of the ambient air temperature.

The results of this computation are shown on Table II and plotted against incident angle in Figure 5 and plotted against $\frac{1}{\cos\theta_i} - 1$ in Figure 6.

7.4 Pressure Drop Test

Results of the pressure drop test are shown in Figure 7.

TABLE I

SOLAR ENERGY SYSTEMS COLLECTOR
THERMAL PERFORMANCE
TEST DATA

275 LBM/HR FLOW RATE

Ambient °F	52.7	52.0	52.7	52.7	52.7	53.0	65.5	66.3
T_{in} °F	52.0	52.0	80.5	80.8	101.0	102.2	140.5	142.0
T_{out} °F	62.7	64.3	90.0	92.2	109.3	112.5	147.2	150.7
Δ T °F	10.7	12.3	9.5	11.4	8.3	10.3	6.7	8.7
Solar Flux BTU/Hr·Ft^2	250	297	250	297	250	297	250	297
Flow Rate Lb/Hr	275	275	274	274	273	273	271	271
Wind Speed MPH	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Efficiency %	62.9	60.9	55.5	56.1	48.3	50.6	38.8	42.4
(Ti-Ta)/I°F·Hr·Ft^2/BTU	0	0	0.111	0.095	0.193	0.166	0.300	0.255

TABLE I (Continued)

Ambient °F	66.7	67.0	54.6	54.6						
T_{in} °F	166.5	166.0	193.7	193.2						
T_{out} °F	171.8	173.3	196.5	197.7						
Δ T °F	5.3	7.3	2.8	4.5						
Solar Flux BTU/Hr·Ft^2	250	297	238	283						
Flow Rate Lb/Hr	268	268	265	265						
Wind Speed MPH	7.5	7.5	7.5	7.5						
Efficiency %	30.4	35.2	16.7	22.5						
(Ti-Ta)/I°F·Hr·Ft^2/BTU	0.399	0.333	0.585	0.490						

TABLE II

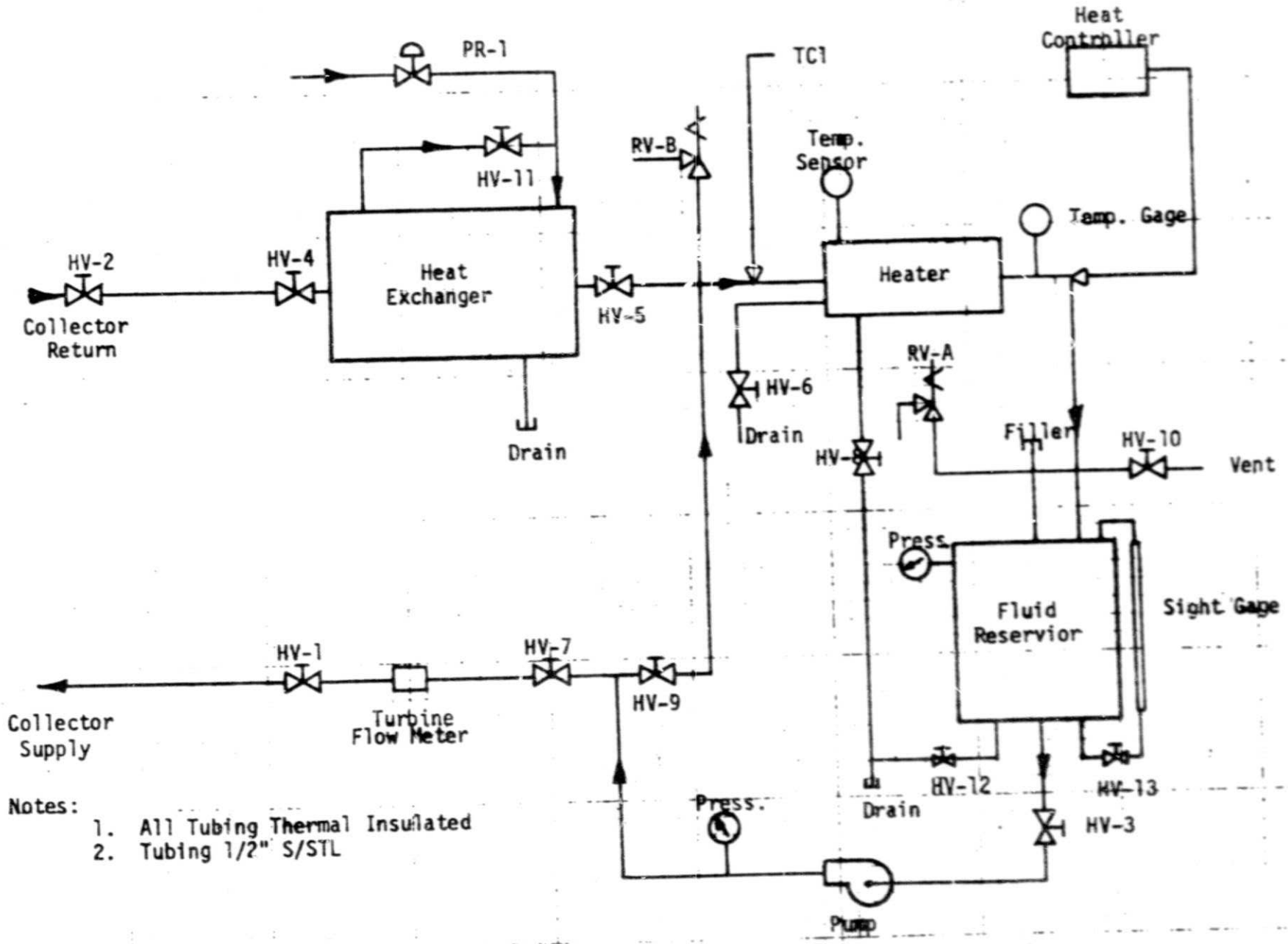
TEST DATA FOR SOLAR ENERGY SYSTEMS COLLECTOR
INCIDENT ANGLE MODIFIER TEST

Incident Angle, degrees	0	15	30	45	60
Ambient °F	65.0	65.4	68.9	65.7	69.0
T_{in} °F	66.0	68.9	70.5	66.6	69.2
T_{out} °F	78.3	80.4	80.6	74.9	74.5
ΔT °F	12.3	11.5	10.1	8.3	5.3
Solar Flux BTU/Hr·Ft^2	287	270	246	195	133
Flow Rate Lb/Hr	275	275	275	275	275
Wind Speed MPH	0	0	0	0	0
Efficiency %	63.0	62.6	60.4	62.6	58.6
$K\alpha\tau$	1	0.994	0.959	0.994	0.930

TABLE III

SERVICE LOAD STEPS
AND TEST RESULTS

Step No.	Load (Lb/Ft^2)	Pass/Fail	Comments
1	10	Pass	
2	20	Pass	
3	30	Pass	
4	50	Pass	
5	80	Pass	
6	120	Pass	



Notes:

1. All Tubing Thermal Insulated
2. Tubing 1/2" S/STL

Figure 1. Collector Liquid Test Loop Flow Diagram

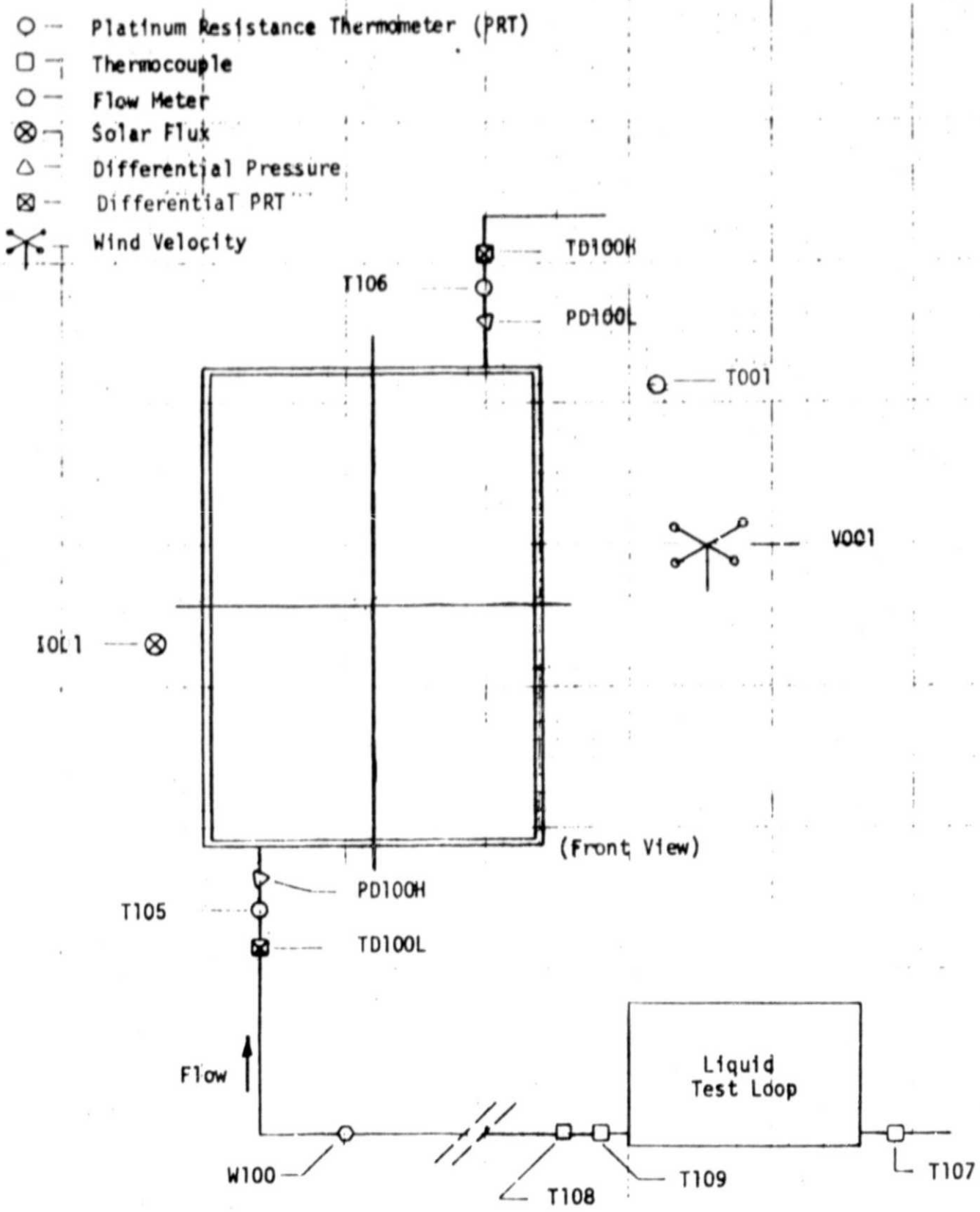


Figure 2. Instrumentation Locations for Solar Energy Systems (Liquid) Collector Test

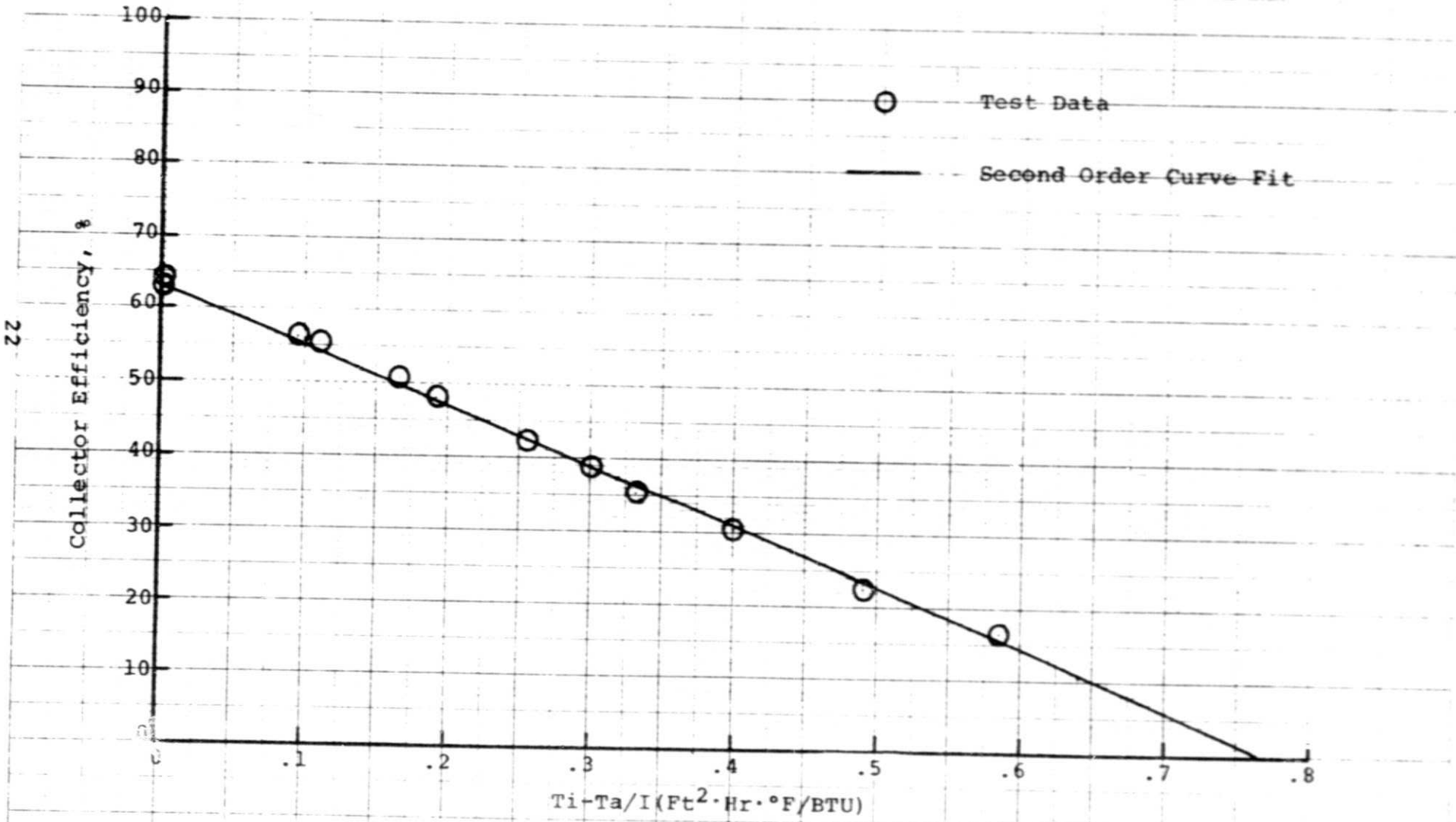


Figure 3. Solar Energy Systems Collector Indoor Thermal Performance Test Results

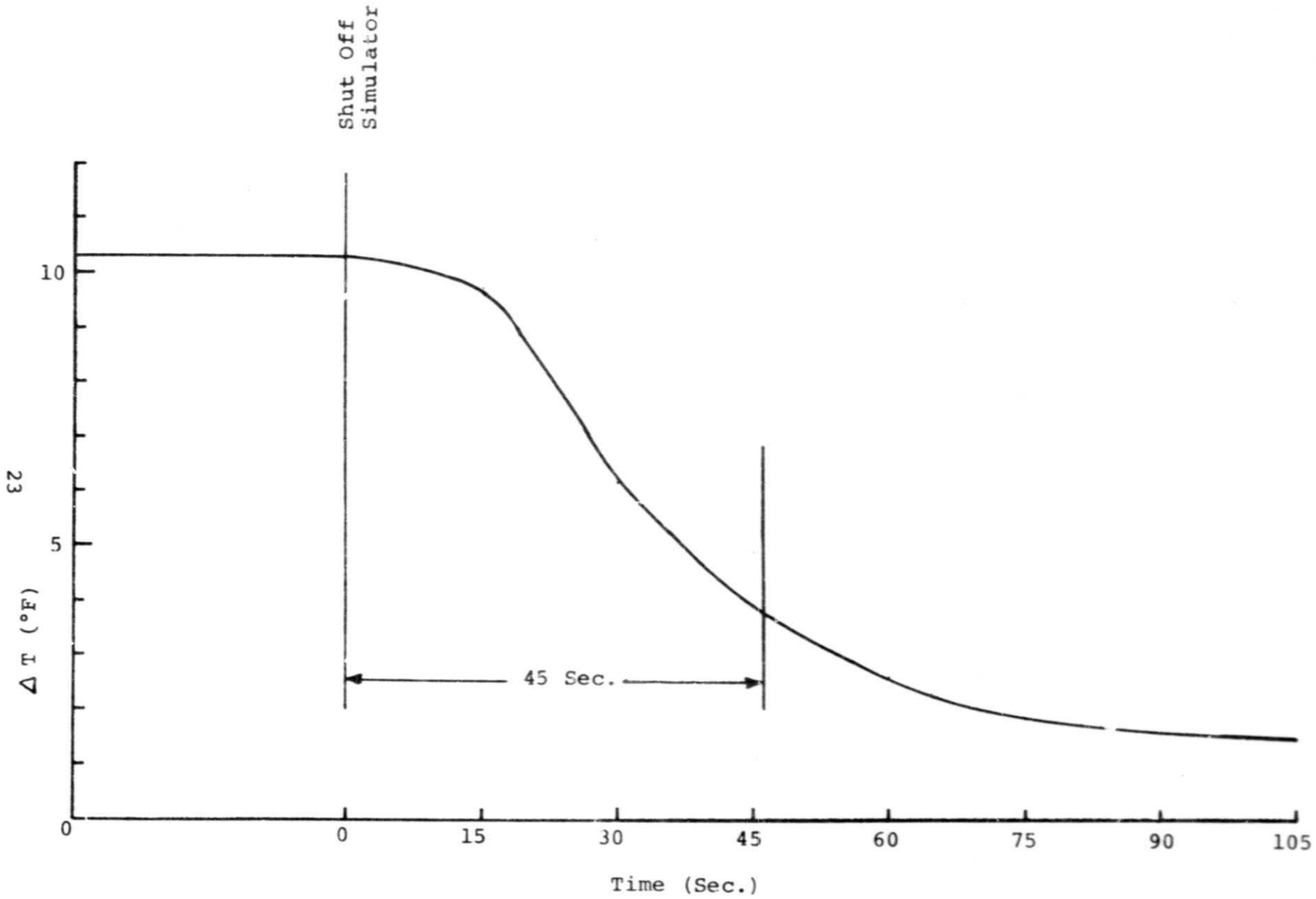


Figure 4. Time Constant Test Results

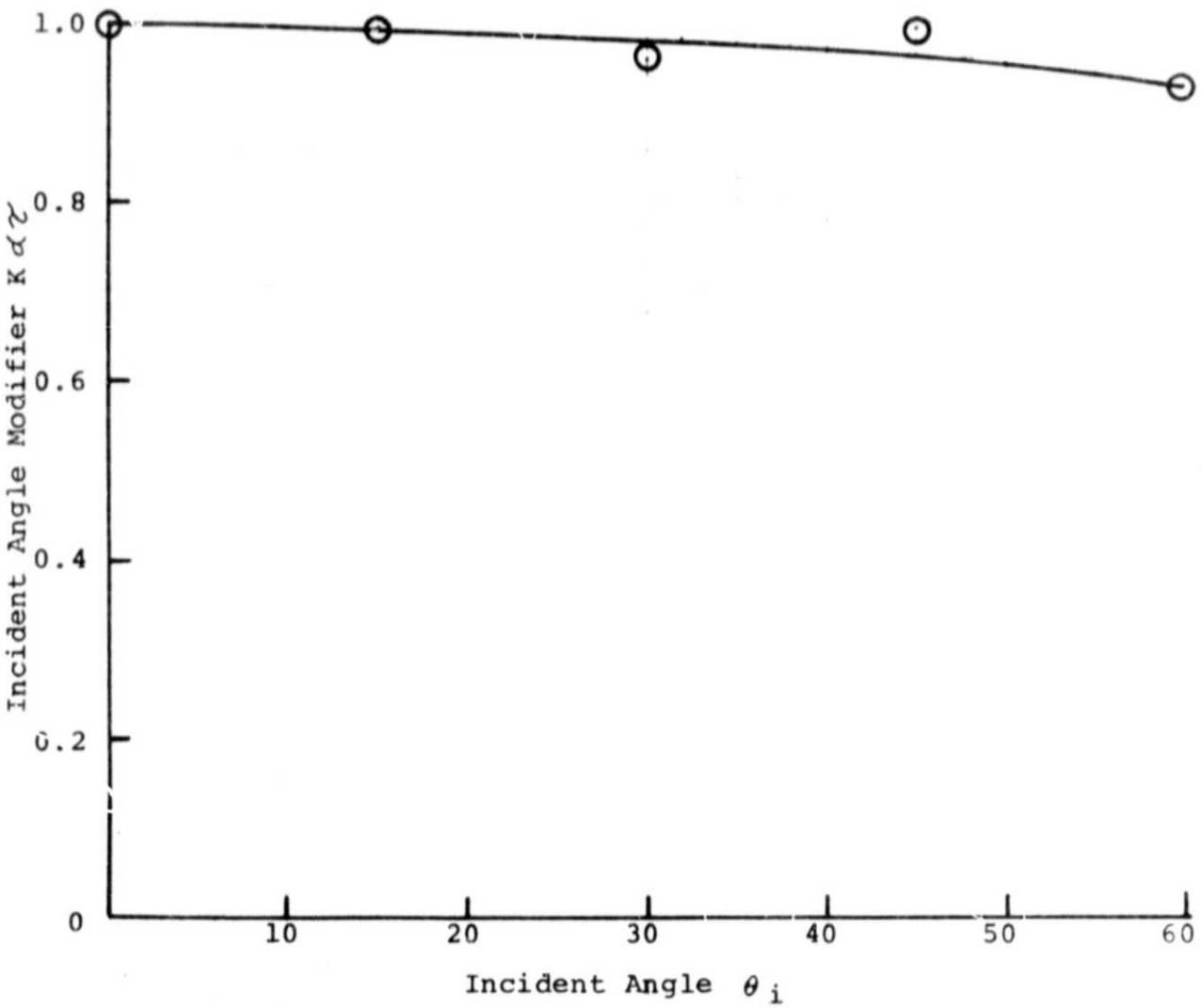


Figure 5. Incident Angle Modifier vs. Incident Angle

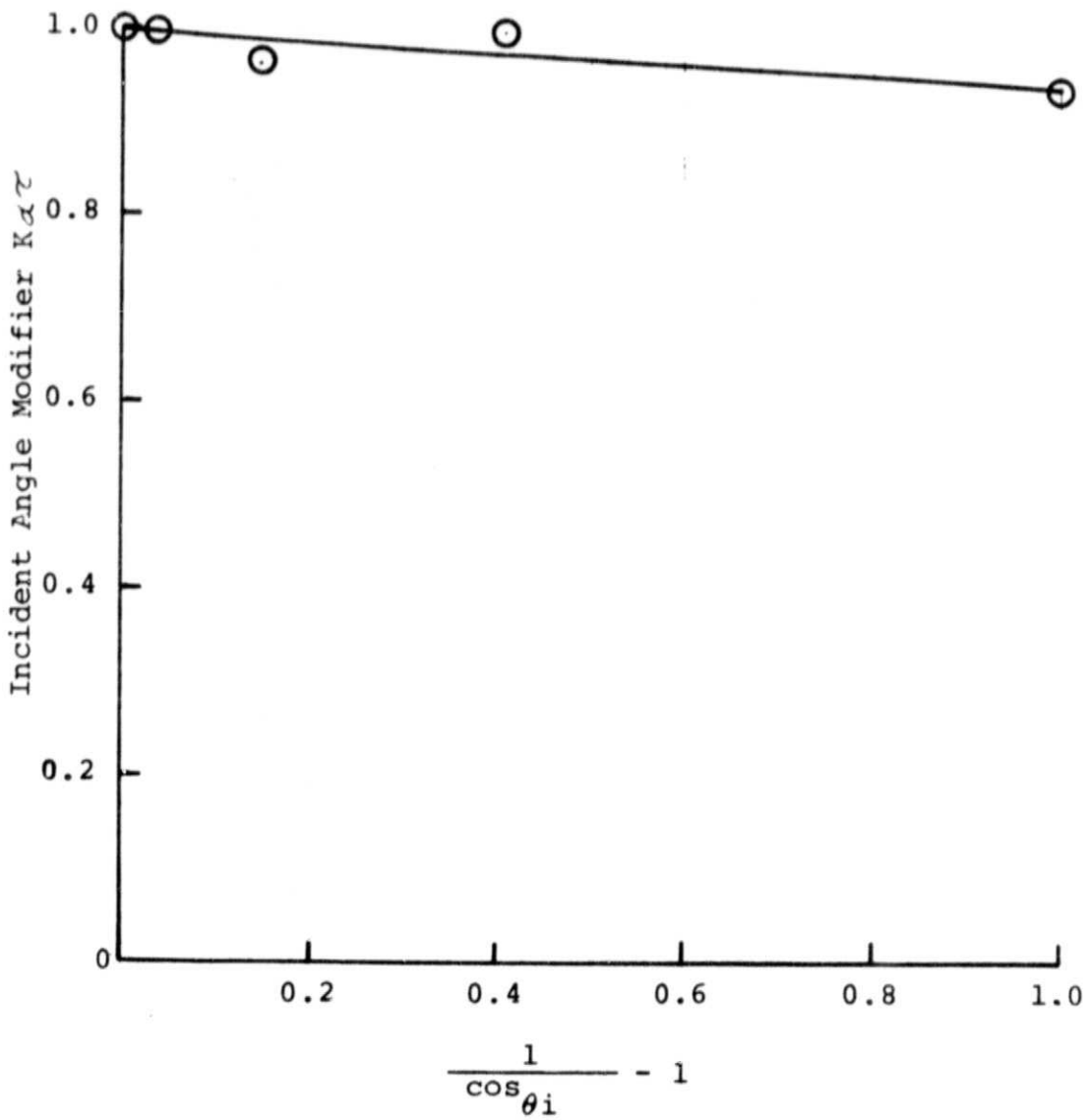


Figure 6. Incident Angle Modifier vs. $\frac{1}{\cos\theta i} - 1$

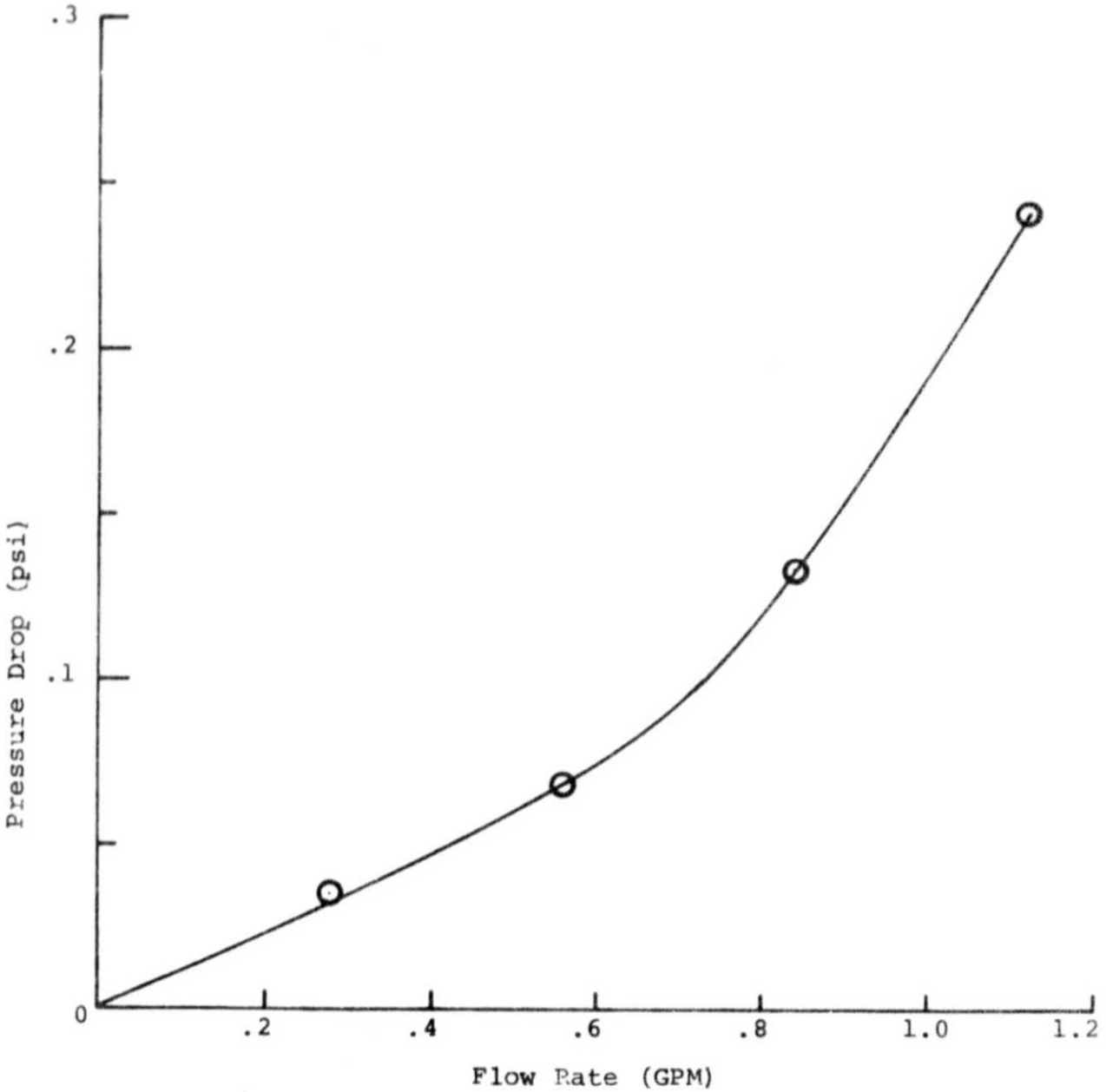


Figure 7. Pressure Drop Test Data

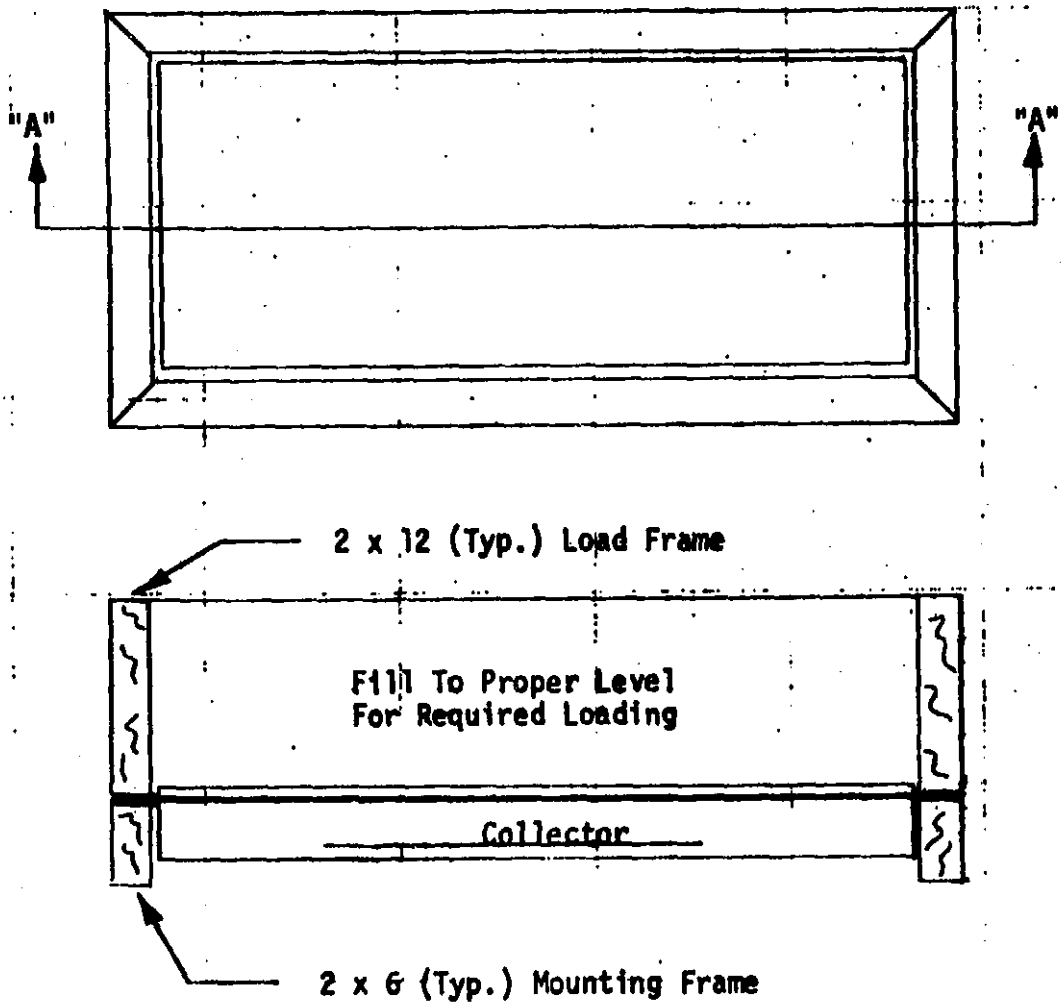


Figure 8. Test Setup for Static Loads

APPENDIX A

SUMMARY

Thermal performance tests were conducted on the Solar Energy Systems double-covered liquid solar collector, following long term exposure to natural weathering conditions. The collector was mounted on the weathering test stand at the Solar Test Facility at Marshall Space Flight Center, Alabama, with exposure to the natural ambient environment. The collector was under stagnation conditions from November 17, 1977, to September 13, 1978. The collector was tested at the Marshall Space Flight Center Solar Simulator on September 15, 1978. The total weathering period was ten months. This collector, although exactly the same model, is not the original collector tested (Reference 2.1). Efforts to precondition a collector resulted in the absorber plate coating's cracking and peeling off within two weeks of exposure on two collectors; therefore, an unweathered collector was originally tested as reported in Reference 2.1. (A)

Visual inspection of the collector, during the weathering test, detected obvious degradation of the absorber plate coating. Within two weeks of initial exposure, the absorber plate coating was cracking and peeling off. At the time of this test, the absorber coating was separated from the plate over the entire surface and was falling off in large pieces as shown in Photograph 1. Minor outgassing effects were evident on the absorber plate and under the inner cover plate. Due to this obvious degradation, the retest was performed in less than a year.

1.0 PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal performance data on a Solar Energy Systems double-covered liquid solar collector under simulated conditions (Reference 2.1), following long term exposure to natural weathering conditions. The tests were conducted utilizing the Marshall Space Flight Center Solar Simulator in accordance with the test procedures specified in Reference 2.2 and the test requirements of Reference 2.3.

2.0 REFERENCES

2.1	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.2	ASHRAE 93-77	Method of Testing to Determine the Thermal Performance of Solar Collectors

3.0 TEST REQUIREMENTS AND PROCEDURES

3.1 Collector Thermal Efficiency Test Requirements

Thermal performance evaluation criteria shall correspond to that of Reference 2.1. Data shall be obtained at inlet temperatures of 0, 25, 50, 75, and 100°F above the ambient temperature at a liquid flow rate of 275 lb/hr (0.55 GPM) at a solar insolation rate of 300 BTU/Hr-Ft^2 and a wind speed of 7.5 mph. The following data shall be recorded during the test at each test condition.

1. Ambient temperature.
2. Collector inlet liquid temperature.
3. Collector outlet liquid temperature.
4. Collector differential temperature.
5. Differential pressure across collector.
6. Liquid flow rate.
7. Insolation rate.
8. Wind speed.

3.2 Test Procedure

1. Mount test specimen on test table at a 45° angle with respect to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 45° with respect to the floor.
3. Align the test table so that the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the top of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all pipes.
5. Assure that data acquisition system is operational.
6. Start liquid flow loop and establish a flow rate of 275 Lb/Hr (0.55 GPM).
7. Establish the wind speed of 7.5 mph.
8. Power up simulator and establish a solar flux level of 300 BTU/Ft^2-Hr.

3.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

3.2 Test Procedure (Continued)

9. Determine the ambient air temperature.

10. Adjust the inlet temperature of the collector to the ambient air temperature value.

11. After steady state conditions have been established, record data for a minimum of five minutes.

12. Repeat steps 9, 10, and 11, changing the liquid inlet temperature as necessary until data has been obtained for each test condition specified in Paragraph 3.1.

13. Upon completion of testing, power down simulator and liquid loop.

4.0 ANALYSIS OF RESULTS

4.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta = \frac{q_u/A}{I} = \frac{\dot{m}\, C_{tf}\, (t_{f,e} - t_{f,i})}{I} \qquad (1)$$

where:

q_u = rate of useful energy extracted from the solar collector (BTU/Hr)

A = Gross collector area (Ft^2)

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$)

$\dot{m}$ = Mass flow rate of the transfer liquid through the collector per unit area of the collector ($Lbm/Ft^2 \cdot Hr$)

C_{tf} = Specific heat of the transfer liquid ($BTU/Lb \cdot °F$)

$t_{f,e}$ = Temperature of the transfer liquid leaving the collector (°F)

$t_{f,i}$ = Temperature of the transfer liquid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta = \frac{(\dot{m}A)C_{tf}\, (t_{f,e} - t_{f,i})}{(IA)} = \frac{\dot{M}\, C_{tf}\, (t_{f,e} - t_{f,i})}{P_i} \qquad (2)$$

Notice that:

$P_i = IA$ = Total power incident on the collector

$\dot{m}A = \dot{M}$ = Total mass flow rate through the collector

Therefore, $\dot{M}\, C_{tf}(t_{f,e} - t_{f,i})$ = Total power collected by the collector.

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta = \frac{Pabs}{Pinc} \qquad (3)$$

where:

Pabs = Total collected power

Pinc = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{Pabs}{Pinc} \times 100 \qquad (4)$$

or from Equation (2), collector efficiency is defined by the equation:

$$\% \text{ Eff} = \frac{\dot{M} C_{tf} (t_{f,e} - t_{f,i})}{Pinc} \times 100 \qquad (5)$$

Each term in Equation (5) was measured and recorded independently during the test.

The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left(t_i - t_a)/I \right)$$

where:

t_i = Liquid inlet temperature (°F)

t_a = Ambient temperature (°F)

I = Incident flux per unit area (BTU/Hr·Ft^2)

The abscissa term $\left((t_i - t_a)/I\right)$ was used to normalize the effect of operating at different values of I, t_i and t_a. The results are shown graphically in Figure 1 with the supporting test data given in Table I.

4.0 ANALYSIS AND RESULTS (Continued)

4.1 Thermal Performance Test (Continued)

Reference 2.3 uses the following terms relating to the thermal efficiency graph:

$F_R(\alpha\tau)$ = intercept of the efficiency curve on the ordinate axis

F_RU_L = the negative of the slope of the efficiency curve

F_R = the solar heat removal factor

α = absorptance of the collector surface for solar radiation

τ = transmittance of the solar collector cover plate

U_L = solar collector heat transfer loss coefficient

A comparison of the before and after weathering efficiency curves indicates that the slope, F_RU_L, did not change significantly; however, the value of $F_R(\alpha\tau)$ did change significantly. With no noticeable change in the transmissivity of the cover plates, the conclusion would be that the overall absorptivity has degraded as a result of the weathering, as indicated by a significant area of the absorber plate with no coating at all.

TABLE I

SOLAR ENERGY SYSTEMS COLLECTOR PERFORMANCE RECHECK
AFTER LONG TERM EXPOSURE TO NATURAL WEATHERING CONDITIONS
7.5 MPH WIND

Ambient Air Temperature (T_a), °F	80.2	79.2	76.1	77.0		
Fluid Inlet Temperature (T_i), °F	85.8	104.7	154.1	191.4		
Fluid Outlet Temperature (T_e), °F	96.2	114.2	160.5	195.6		
Differential Fluid Temperature (ΔT), °F	10.4	9.5	6.4	4.2		
Total Solar Flux (I), BTU/Hr·Ft^2	299.0	299.0	297.7	297.7		
Flow Rate, GPM	.554	.574	.544	.554		
$(T_i - T_a)/I$ °F·Hr·Ft^2/BTU	0.019	0.085	0.262	0.384		
Efficiency (η), %	51.3	48.4	30.6	20.2		
Specific Gravity	0.997	0.993	0.980	0.967		

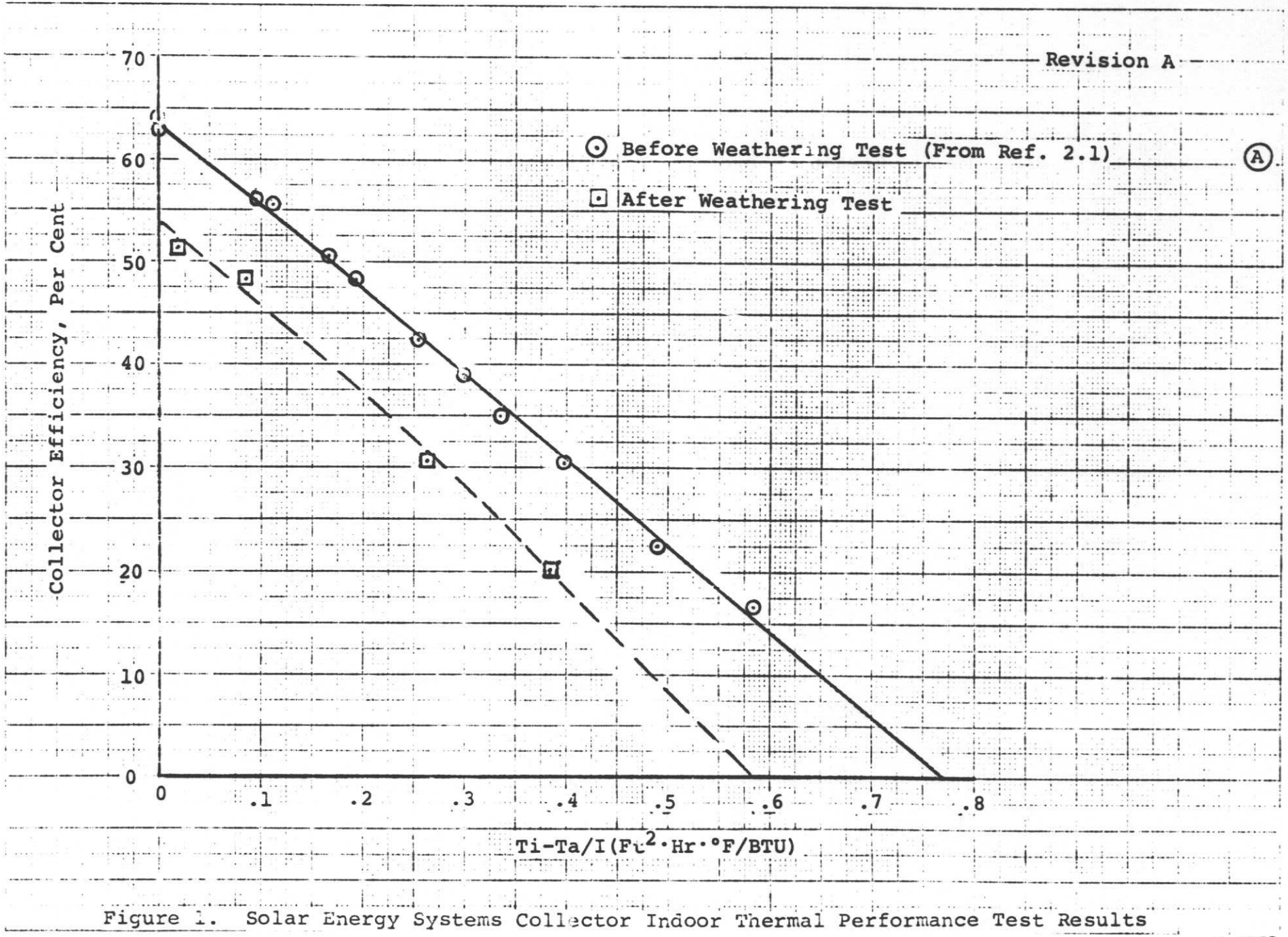
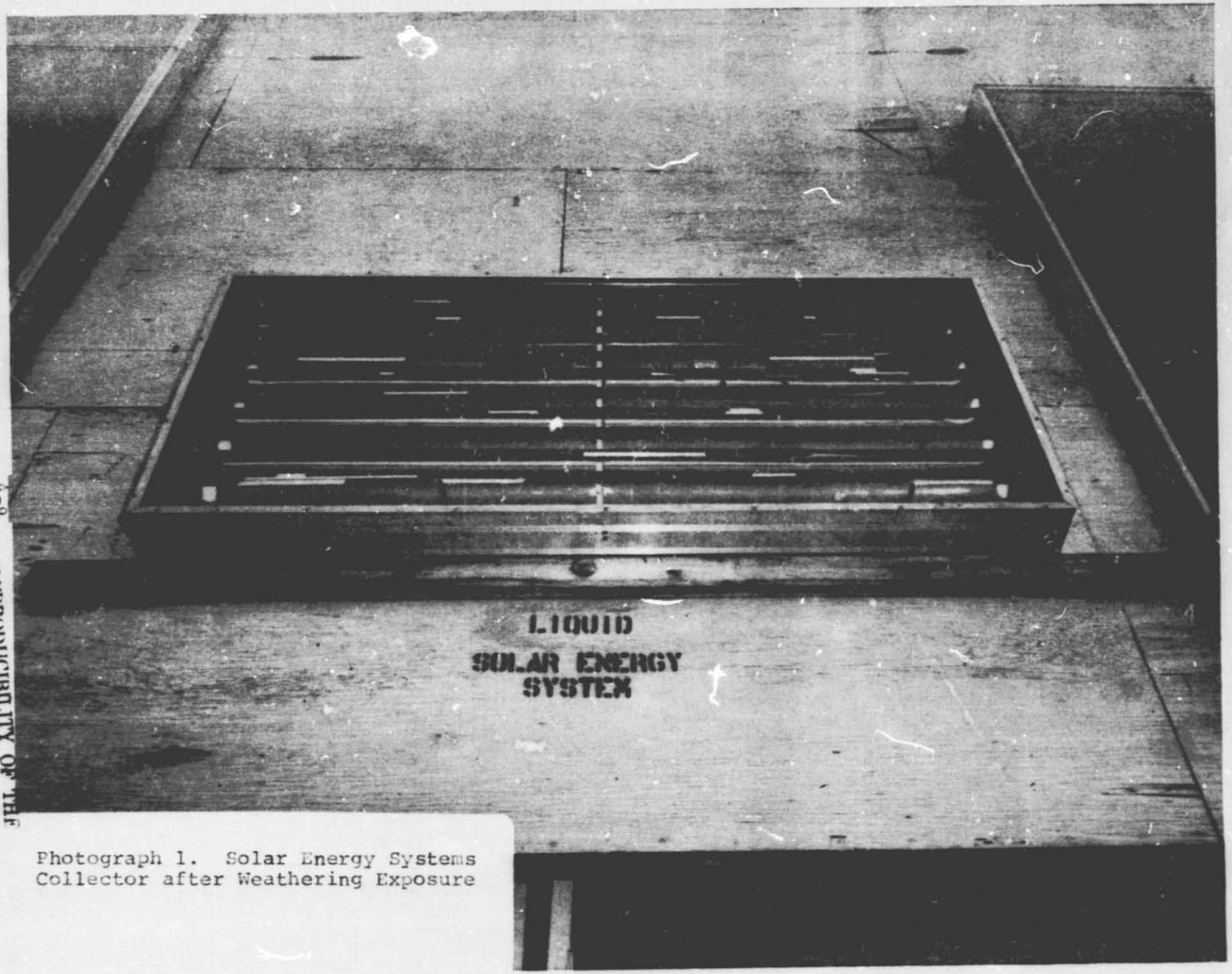


Figure 1. Solar Energy Systems Collector Indoor Thermal Performance Test Results

NASA-MSFC



Photograph 1. Solar Energy Systems Collector after Weathering Exposure

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